International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 9, Issue 3, Jun 2019, 1003-1014

USING FUZZY LOGIC SYSTEM TO OPTIMIZE MEASURING POROSITY BY AERODYNAMICS SENSOR

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ABSTRACT

Porosity is a measure of the void spaces in a material and is a fraction of the volume voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. Many methods have been developed for determining porosity. Most of the methods developed have been designed for small samples, it is the need to determine the bulk volume, pore volume and the volume of its solid matrix for the sample. The direct and indirect methods are based on volume determination and measuring of some properties of the void space respectively.

In this paper an aerodynamic sensor related to the indirect determination porosity method was designed to measure in-process grinding wheel porosity. The fuzzy logic control system was used to optimize the best design and dimensions for best transducer reception out of the porosity variations. A computational fluid dynamic package used to design the sensor parameters, and to simulate different pours wall to be measured. An experiment made with different porosity levels grinding wheels to validate the theoretical method. The results provide the ability of the sensor to detect wall porosity up to 0.05 %, also. Composites mesh, sponges, rocks and other pours surfaces can be future research candidates.

KEYWORDS: Measuring Porosity, CFD, Fuzzy Logic Control System & Aerodynamic Sensor

Received: Mar 21, 2019; **Accepted**: Apr 11, 2019; **Published**: May 22, 2019; **Paper Id**.: IJMPERDJUN2019108

Original Article

1. INTRODUCTION

Porosity is one of the factors that influences the physical interactions and chemical reactivity of solids with gases and liquids for many industrial applications. Examples of industrial important porous materials include catalysts, construction materials, ceramics, pharmaceutical products, pigments, sorbents, membranes, electrodes, sensors and many other objects (1).

Several methods can be employed to measure porosity (2)

- Direct methods (determining the bulk volume of the porous sample, and then determining the volume of the skeletal material with no pores (pore volume = total volume − material volume).
- Optical methods (e.g., determining the area of the material versus the area of the pores visible under the microscope). The "areal" and "volumetric" porosities are equal for porous media with random structure (3).
- Water saturation method (pore volume = total volume of water − volume of water left after soaking).

- Water evaporation method (pore volume = (weight of saturated sample − weight of dried sample)/density of water)
- Mercury intrusion porosimeter (several non-mercury intrusion techniques have been developed due to toxicological concerns, and the fact that mercury tends to form amalgams with several metals and alloys).
- Gas expansion method (5). A sample of known bulk volume is enclosed in a container of known volume. It is connected to another container with a known volume which is evacuated (i.e., near vacuum pressure). When a valve connecting the two containers is opened, gas passes from the first container to the second until a uniform pressure distribution is attained. Using ideal gas law, the volume of the pores is calculated as

$$\varepsilon = \frac{V_v}{V_T} \tag{1}$$

where

Volume fraction of porosity (ε) can be defined as the fraction of void space (V_v) relative to the apparent total bulk volume (V_T) of the sample (6). For a single-phase material, the value of V_v can be obtained from the difference between the volume of the solid (computed from its crystal lattice density) and the apparent total bulk volume V_T of the sample:

The large variety of porous structures and industrial applications has led to the development and use of many experimental techniques for determining the various characteristics of porous solids (7).

For fast and accurate porosity vision-based inspection is presented a fuzzy logic control system used (8). The proposed method is based on the correlation of the core of pore candidates with twelve developed matrices resulted in five novel features. The fuzzy decision making on porosity detection adds great value to the whole production system, by increasing the confidence of the inspectors in the machine performing real-time verification.

Fuzzy curve analysis based on fuzzy logics is used for selecting the best related well logs with core porosity and permeability data (9). The results show that the technique can make more accurate and reliable reservoir properties estimation compared with conventional computing methods. This intelligent technique can be utilized a powerful tool for reservoir characterization from well logs in oil and natural gas development projects.

Predicting porosity and permeability from the compositional and textural characteristics of sandstones used Fuzzy logic control system presented in (10). Fuzzy modelling is a linguistic paradigm based on fuzzy logic, rooted in the theory of fuzzy sets. The essentials of fuzzy modelling are explained using an example in which porosity and permeability values of a sandstone are predicted from five compositional and textural attributes.

A modelling method based on a fuzzy-logic algorithm to establish aerodynamic models by using the datasets from flight data recorder (FDR) (11). The fuzzy-logic aerodynamic models are utilized to estimate more accurately the nonlinear unsteady aerodynamics for a transport aircraft, including the effects of atmospheric turbulence. The robustness and nonlinear interpolation capability of the fuzzy-logic algorithm are demonstrated in predicting the degradation in performance and stability characteristics of this transport in severe atmospheric turbulence with sudden plunging motion.

The aim of this research is to implement an aerodynamic sensor to measure the porosity level and percentage of pours surfaces.

The ratio of holes to solid that the wind. Aerodynamic porosity is less than visual porosity, by an amount that depends on the constriction of holes and density of it among the measured surface.

2. METHODOLOGY OF THE PAPER WORK

2.1. Sensor Design

- Use a fuzzy logic system to optimise the best dimensions values (inner diameter of the sensor, sensor total length, pressure transducer location and finally the sensor slope).
- Applying this design by the Fuzzy on a CFD package to verify the fuzzy results.

2.2. Porosity Measurement Work

- Laboratory experiments to measure the porosity of grinding wheels by the new aerodynamic sensor for measuring porosity (ASP). That is manufactured with respect to the recommended dimensions given by the Fuzzy system and CFX package.
- Using the CFX simulation to verify the experimental results on the grinding wheels of ASP sensitivity for measuring porosity.

3. THEORY OF THE AERODYNAMIC SENSOR

The principal of aerodynamic sensor for measuring porosity (A.S.P.) depends on using high-response miniature transducer to capture the variation of static pressure when the air issuing from the nozzle impinges on the object surface [6]. The sensor anvil is located at a certain distance from the working surface of the measured item. This distance was predetermined to ensure effective response from the transducer. Figure 1 shows the flow of pressurised air passing through the sensor was directed by the sensor nozzle to a project area. When the air strikes the solid wall, static pressure fluctuation is around and inside this sensor. The pressure transducer (*Kulite* XCQ093, 25A, 300KHz) with sensitivity 3.5mV/psi, measures that static pressure which is a response to several parameters including the wall distance as well as wall surface topography.

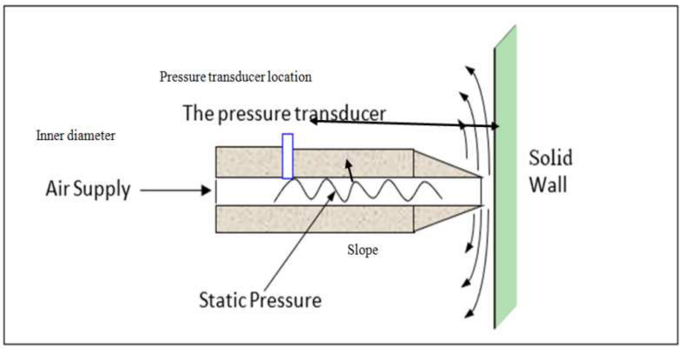


Figure 1: Sensor Characteristics

4. FUZZY LOGIC CONTROL SYSTEM METHOD FOR OPTIMISING THE SENSOR DIMENSIONS

A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to a scalar output data (12). A FLS consists of four main parts: fuzzifier, rules, inference engine, and defuzzifier. These components and the general architecture of a FLS is shown in Figure 2.

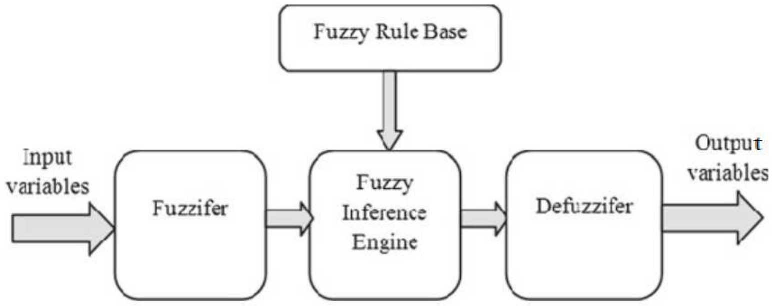


Figure 2: Architecture of Fuzzy Logic Control System

The process of fuzzy logic is explained (13) firstly, a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification. Afterwards, an inference is made based on a set of rules. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step.

Using fuzzy logic control system to determine the most significant variables in sensor dimensions and design. This is to eliminate the number of experiments to carry out and to achieve the best dimension values.

The fuzzy logic control system modelling used in this paper accomplished in five steps:

- Identification of input and output variables. In this paper, the inputs are five compositional and textural parameters, namely: relative amounts of ductile grains, rigid grains and detrital matrix, together with grain size, and the Trask sorting coefficient. The output is either porosity or permeability.
- Fuzzy clustering of output values.
- Formation of membership grades of input data.
- Generation of fuzzy rules.
- Prediction via fuzzy inference

The inputs to the fuzzy logic control system used were inner diameter, total length and slope of the sensor, also the pressure transducer location input to the fuzzy system to determine the captured static pressure value at the pressure transducer location P_o*. The range of inputs and outputs used in fuzzy system shown in Table 1.

Table 1: Inputs and Output of Fuzzy Logic Control System

Experiment No.	Pressure Transducer Location	Sensor Slope	Sensor Inner Diameter	Sensor Total Length	Static Pressure P_o* bar
1	15	5	0.3	50	0.6318
2	15	15	1	60	0.178
3	15	30	2.5	70	0.1861
4	25	5	1	70	0.3055
5	25	15	2.5	50	0.0872
6	25	30	0.3	60	0.6437
7	40	5	2.5	60	0.1946
8	40	15	0.3	70	0.5196
9	40	30	1	50	0.3428
					ΣT=3.089

The Structure of the fuzzy control system used is shown in Figure 3. The inputs and outputs of the system appear in the structure.

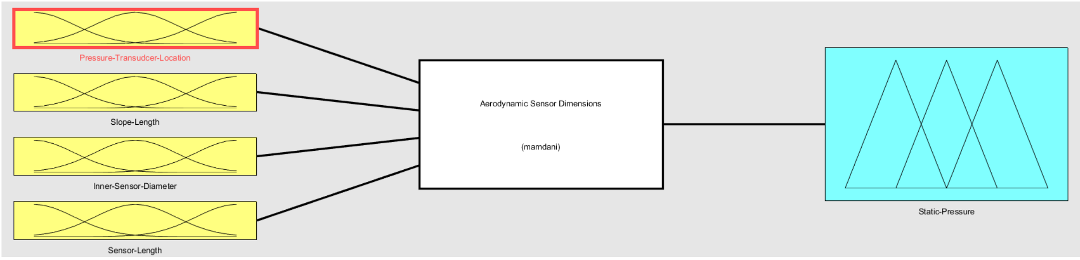
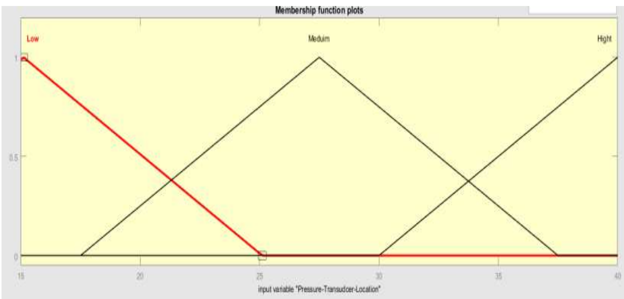
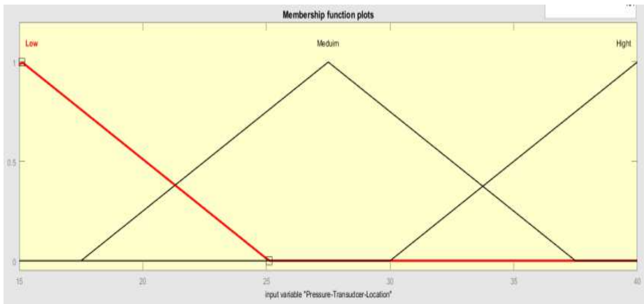


Figure 3: Structure of Fuzzy Control System

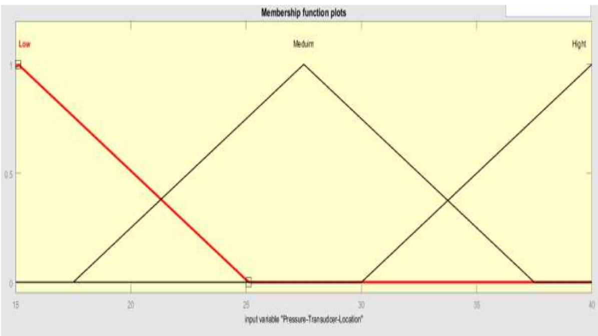
Related to Table 1 the inputs and output of the fuzzy logic control system have three ranges low, medium and high ranges. This ranges shown in Figure 4, where (a), (b), (c) and (d) explain the ranges of four fuzzy system inputs and (e) show the ranges of the system output.



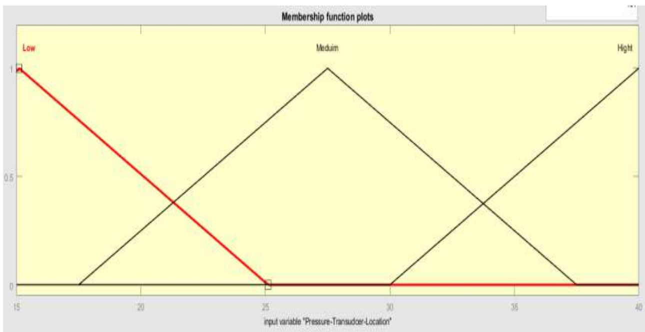
(a) First Input, Pressure Transducer Location



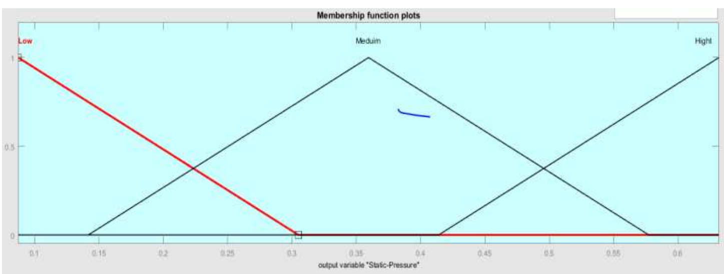
(b) Second Input, Slope Length



(c) Third Input, Inner sensor Diameter



(d) Fourth Input, Sensor Length



(e) Static Pressure Output

Figure 4: Low, Medium and High Ranges of Inputs and Outputs Fuzzy Logic Control System

The membership functions that used in the sensor dimension identification, fuzzy logic control system shown in Figure 5.

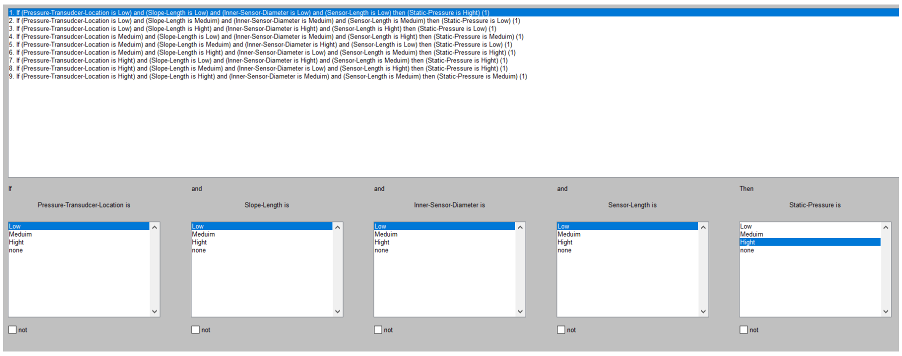


Figure 5: Membership Functions of Fuzzy Logic Control System Used

The final optimization dimensions of the sensor that get by using fuzzy control system shown in Figure 6.

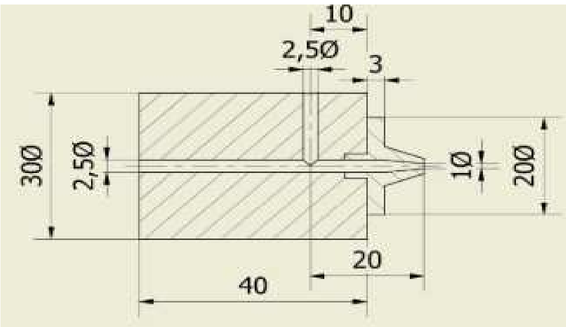


Figure 6: Final Sensor Dimensions Given by Fuzzy Logic Control System

5. CFX SPECIFICATIONS

A Computational Fluid Dynamic Package (CFX) used to simulate the aerodynamic sensor design and verify the best design parameters given by the Fuzzy results. To optimize better sensor accuracy, Repeatability and performance.

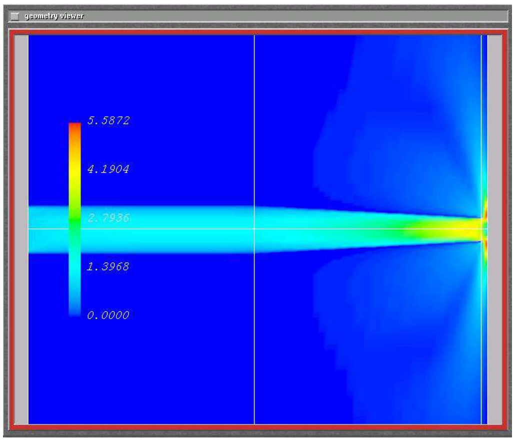


Figure 7: Illustrates the Ability of CFX to Simulate the Aerodynamic Effect on the Sensor and the Measured Surface

As it is shown in Figure 7 the air pressure strikes the pours wall in the far right of the photo. Some of the air breaks through the pours part of the wall with the yellow and red colors. The rest of the pressurized air reflects by the solid

part of the wall. Either returns to the inner diameter of the sensor (as a static pressure) or dispersed outside the sensor.

The CFX results confirms fuzzy logic control system results as shown in Figure 6.

The aerodynamic sensor for measuring porosity (ASP) design parameters as shown in Figure 6 were 2.5mm input diameter converted to 1mm output diameter along 10mm slope length with 40mm total length, the pressure transducer supported at 20 mm away from the nozzle tip.

6. POROSITY MEASURING

The implemented work in this paper depends on theoretical technique and experimental technique. Regarding the practical part, laboratory experiments were made using different grinding wheels with different porosity. The ASP is to identify the porosity level of the measured wheels. Theoretical technique, in terms of CFD package examines the sensor capability of measuring grinding wheel porosity using verifying the experiments results.

6.1 Porosity Measuring by Laboratory Experiments

The experimental technique used a different grinding wheel types included in test rig contains grinding machine, drives with control units, measuring devices and operating system software. As shown in Figure 9. The signals output of the sensor transducer is received by operational amplifier, sent to a filter to exclude noise, and then was displayed on a pc screen using LabView program as shown in Figure 9.

Figure 8 illustrates the test rig that used in this research. The system consists of four main parts, sensor ASP and its amplifier, grinding wheel (measured object) and operating system hard ware signal filter and software to represent and analysis data (LabVIEW).

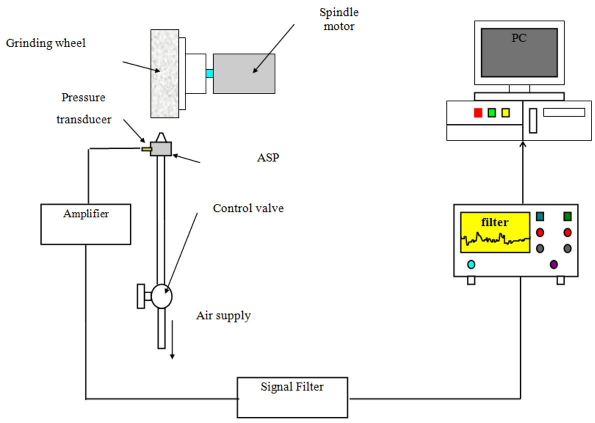


Figure 8: Illustrates a Sketch of the Experiment Test Rig

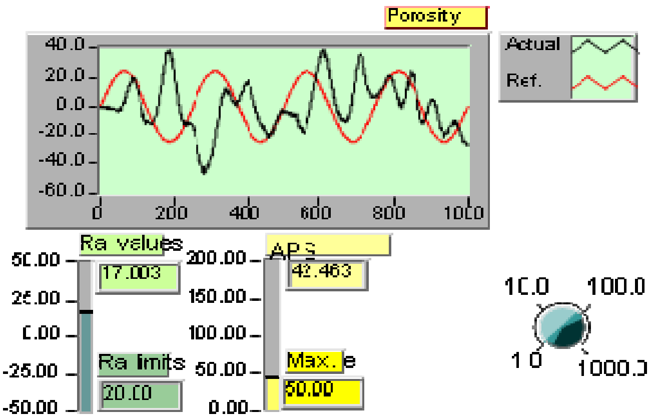


Figure 9: LabVIEW Display for APS Porosity Readings

Figure 9 Using LabVIEW interface for the following reasons to display the received signals, analyses the data statistically, and to add filters for the noise may escaped from the previous hard ware filter.

The grinding wheels all from the same manufacturer with the same grain size, bond and surface roughness. Having the same distance from the measuring nozzle and with the same abrasive material. The only variable is the wheel structure (porosity) as shown in Table 2.

Table 2: Grinding Wheel Different Porosity and ASP. Readings

Grinding Wheel Number	Abrasive Type	Grain Size	Grade	Structure	ASP. Reading (mV)	Bond Type
1	A	36	L	3	4.5	Vitrified
2	A	36	L	8	3.5	Vitrified
3	A	36	L	11	2.5	Vitrified
4	A	36	L	16	1.2	Vitrified

7. RESULTS AND CONCLUSIONS

Excluding the eccentricity and roughness noise of the wheel the sensor identifies the different wheel porosity levels as shown in Figure 10. Giving an accuracy of 2% of the porosity changes. This accuracy is due to the pressure transducer as well as the amplifier accuracy.

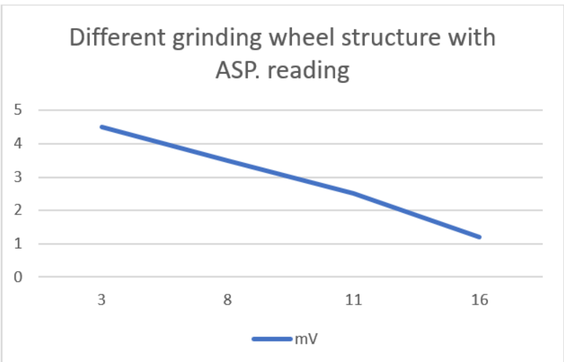


Figure 10: Relation between Grinding Wheel Porosity and ASP Reading

Creating pours surface by the CFX. As in Figure 10, Exploring a 4-bar pressure to these surfaces by the flapper nozzle (ASP.) porosity range simulated by the program ranges from 5%-90% porosity getting the following readings that shown in Table 3.

Table 3: Different Porosity Level Varies to CFX Simulation Readings

Surface Porosity Percentage (%)	CFX-Nozzle Reading (mV)
5	222
30	164
50	146
70	104
90	45

In Figure 11. Results giving by the CFX using the same sensor dimensions and the grinding wheel conditions give almost the same trend of the actual sensor reading. However the simulation gives better accuracy up to 1 % of porosity change rather than 2 % of the practical reading. That can be referred to noise or signal distortion in the lab readings.

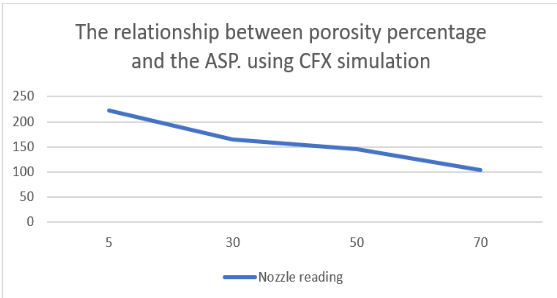


Figure 11: Prosoity Values (%) by ASP. Sensor and CFX Simulation

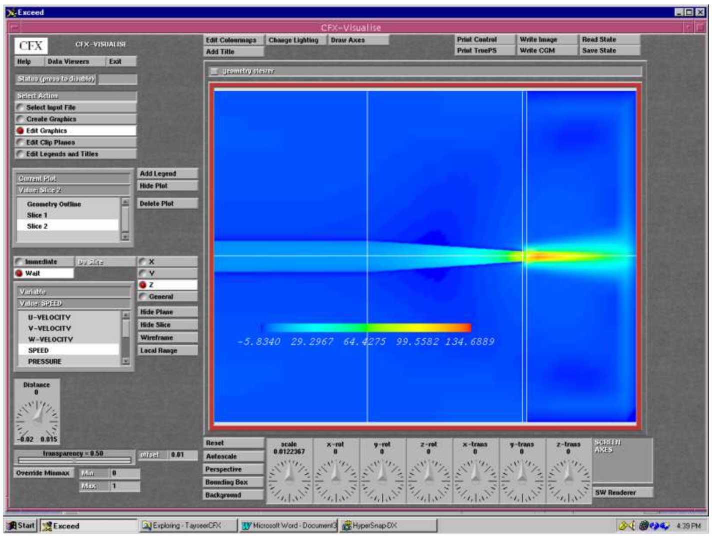


Figure 12: Normal Velocity Distribution for Measuring 70% Porosity

Figure 12. Simulation of the CFX air behaviour on of the 70% pours surface should how is most of the air breaks through the pours wall and less returns back to the transducer to capture. The more pours is the surface the less static pressure returns back to the sensor, the less volts giving by the transducer.

8. CONCLUSIONS AND FUTUTRE RECOMMENDATIONS

The method discussed in this paper is easier, less expensive than many other methods of measuring porosity, and can be operated on line production, unlike other methods that may be more accurate but need special equipment and measured workpieces should be transferred to the measuring lab.

8.1 Conclusions

This paper introduces a new method for measuring porosity by aerodynamic theory know as ASP;

- Optimization of the sensor was made by the fuzzy logic system and verified by CFX package to achieve the best dimensions and design. This leads to the best captured pressure by the transducer and so the best sensor accuracy.

Experimental measurements were made on different grinding wheels with different porosity percentages. The results showed that the sensor can detect the porosity percentage up to 2 %.

- A simulation was made by computational fluid dynamic CFX. The sensor can detect the wall porosity up to a theoretical accuracy of 0.003 bar/1% porosity, this is 150mV/ or 1 % change in porosity

Some of this sensor advantages are;

The sensor has no physical contact with the measured workpiece. Therefore, there is no effect of the measuring force error, or destructive measuring technique.

- Can give porosity measurements on the production line. You do not have to bring the measured object to the lab to be measured

8.2 Future Recommendations

More pours objects needed to be measured such as ceramics, composites, rock to answer the following questions;

- What is the scope of measured objects that the ASP can cover?
- What are the measuring conditions of these objects?
- What is the ASP working range and repeatability and response time?

Validation for ASP measurements on grinding wheels should be made by a well-known method of measuring porosity as a bench-mark. To compare the ASP accuracy, repeatability and working range. With an old classic method of measuring porosity.

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